CONSULTING ENGINEERS AND TECHNOLOGICAL INNOVATION IN THE CANADIAN ARCTIC OFFSHORE PETROLEUM INDUSTRY*

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Consulting engineering and design organisations, known as CEDOs, are responsible for much of the extensive technological innovation in the Canadian arctic offshore petroleum industry over the past decade. This research is an exploration of the roles CEDOs play in the innovation process in ocean engineering systems. The CEDOs are not strong in organising the project actors, or in supplying project execution services, but they play a wide variety of crucial roles as the source of innovation, in design and in the overall evolution of technology.

Keywords: consulting engineering, technological innovation, offshore petroleum

INTRODUCTION

This article reports on some aspects of research on consulting engineering firms and technological innovation which was done by a case study of the Canadian arctic offshore petroleum industry (AOPI). The purpose of the article is to investigate the roles of consulting engineering firms in technological innovation.

Consulting engineering is an invisible industry. It does not construct, operate or own much industrial technology. Instead, its primary activity lies in design and transfer of technology and it works on a contract basis. While governmental and industrial users of consulting engineering services may be well aware of the importance of this industry, it is generally true that technology policy makers and academic researchers are ignorant of its function and characteristics.

The bulk of research on consulting engineering has been done in the context of international development and technology transfer to the

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Third World. Araoz[1] is the latest major initiative in this area and summarises the previous studies. The literature has settled on the term CEDO for Consulting and Engineering Design Organization and that will be used here. It focusses on CEDOs in countries with little industrial base and is very case-specific. Aside from its input to definitions and typology of CEDOs, it is of limited use to structure analysis in the AOPI context.

The study of CEDOs in industrialised countries is very limited. Perrin[2] seems to be the only one to have made detailed studies. The OECD began a study of CEDOs but it was focussed on the international development issue and seems not to have been completed.[3]

The Canadian CEDO context is only beginning to be researched. However, the emphasis is still on international development.[4] Some statistical data exist[5] but they are based on a definition of consulting engineering which is quite different from the definition of CEDO, so they are only of limited value.

In short, the study of CEDOs is a very new and undeveloped field. There is not yet a consensus on the definition of a CEDO, there are few data on which to base analysis, and there is little theoretical structure to explain their functioning and importance. The existence of CEDOs has not yet been noticed by either the innovation literature or the industrial organisation literature although it could be a major issue for them to explore.[6] The innovation literature almost universally assumes the innovation process to be carried out by individual firms that own or manufacture the new technology. Industrial organisation theory has generally not been concerned with the question of technology development.

The lack of attention to the AOPI and CEDOs is unjustified. Canada has a substantial CEDO industry; 3 of the 10 largest firms in the world are Canadian,[7] and the industry is largely Canadian owned and controlled. In the specific case of the AOPI, there is a great deal of Canadian controlled innovation in technology taking place which involves significant CEDO participation.

Because so little is known about this topic, the approach taken here to the research is oriented towards exploration and development of hypotheses about CEDO dynamics.[8] There are two reasons for this: first, it is necessary to attempt to transcend the severe limitations of prior research which has often been too case-specific; second, we need to gain a picture of the overall pattern of innovation in the AOPI instead of initially studying details of a few new technologies. This means the analysis and data base are broad rather than deep, and that the ideas presented in this report are not conclusively tested. Rather, they are given as reasonable conjectures supported by limited data, but data which are in harmony with the overall pattern of development of the entire industrial sector. In fact, the research was able to investigate all petroleum companies, all marine innovations and all the major CEDOs in the AOPI. This research has been conceived as an initial attempt to sketch out a wide and coherent framework for the CEDO roles in innovation which serves as a base for theorising about CEDO dynamics. Subsequent research in the AOPI and in other industries can take this base and test it more thoroughly.

The work reported on here is only a part of a larger research program on innovation and industrial organisation. This explains partly why the work stops at presenting reasonable hypotheses. Had it been the only subject of investigation, some of the issues would have been addressed by more quantitative data gathering. However, obtaining data on CEDOs is extremely difficult; none of the AOPI petroleum firms kept any accessible records — the CEDO issue was simply regarded as not important enough to do so. Data would have been released in most cases, but it would have required going back to the individual expenditure forms in accounting departments. Thus, quantitative data gathering was limited and fortuitous, and the research relied mostly upon extensive interviews with key actors. In all, 26 interviews were conducted with CEDO designers and managers, 32 with petroleum companies and 17 with government and universities.

THE CASE STUDY

Before analysing the innovation roles, some information must be given on the industrial context of the AOPI and on the innovations studied. The industry began in the late 60's when petroleum finds in land areas of the Canadian arctic were seen to extend offshore into ice covered waters. All the offshore activity over the period studied, from 1969 to 1982, was handled by the small group of petroleum companies listed in Table 1. All the firms dealing with the arctic offshore are located in Calgary, forming a distinct subgroup within the larger petroleum industry community in Canada.

The AOPI is fundamentally based on technological innovation; initially no exploration, production, or transportation activities were possible with existing systems. A substantial effort by each company has been made to develop new technological systems that would allow operations in the particular geographical conditions of its lease areas. The process of innovation can be summarised as an attempt to modify existing technologies for use in arctic ice although, over the approximate decade studied, whole new systems have been developed. Table 2 summarises the innovations studied. They consist of surface platforms, bottom founded platforms and vessels, involving civil, ocean and mechanical engineering technologies. These 19 innovations represent all the new systems created in these fields by the AOPI over the period of study.

TABLE 1.

The Petroleum Firms Constituting the AOPI

Firm	Parent	Ownership of Parent	Employees in Parent Firm
Esso Resources Canada	Imperial Oil Ltd.	American	14,753 (1)
Gulf Canada Resources Inc.	Gulf Canada Ltd.	American	11,000 (3)
Suncor Resources	Suncor Inc.	American	4,311 (2)
Arctic Pilot Project	PetroCanada (major proponent)	Canadian Crown Corporation	2,200 (2)
Canadian Marine Drilling	Dome Petroleum Ltd.	Canadian	1,129 (1)
Panarctic Oils	Panarctic Oils	Canadian	152 (1)

Source: (1) Financial Post, *Survey of Energy Resources*, Toronto, Financial Post, 1978;
(2) Nickle, C., *Nickle's Canadian Oil Register 1980-81*, C.O. Nickle Publications, Calgary, 1980.
(3) Dunn and Bradstreet International, *Principal International Business*, 1981.

Of course, there has been substantial innovation in other technologies in the AOPI — electronics, pollution, remote sensing, surveying — but their investment in terms of money and manpower is tiny compared to the $3,500 million the platforms and vessels represent.[9] Science and basic research play only minor roles in this process of incremental modification and adaptation of existing arctic land systems and North Sea offshore technology. New technical knowledge is only generated after the testing and use of the structures. It is important to note that these systems are produced in one-off quantities, or at most, several identical examples. With their large physical size and great expense, they are quite different from most of the technologies reported on in the innovation literature. These characteristics should be remembered when attempting to relate the CEDO roles in the AOPI to other industries.

Table 2 lists 19 innovations, but there are actually many more, because this table lists only at the system level. For example, the Panarctic platform is classed as one system innovation, but it is made up of three innovative subsystems — the ice platform, the drill rig, the subsea equipment — and each of these subsystems embodies several more innovations. This conception uses a picture of technological innovation as a hierarchical process whereby engineering design

TABLE 2

Innovation Summary

Technology System	Project State Attained (Dec 1981)	Estimated Cost $m	Corporate Developer
Family 1: Bottom Founded Platforms			
gravel and sediment fill islands	operations and decommissioned		Imperial
small island		2-15	
biggest island		60	
total for 16		200	
steel core fill island	decommissioned	5	Sun
caisson retained islands			
octagon	detailed design	27	Imperial
Dome caisson	operations	14(1)	Dome
island in place		60-70	
Gulf caisson	construction	200(1)	Gulf
berm		50	
monocone gravity platform	predesign	100-200	Imperial
arctic production & loading atoll	predesign	1,000	Dome
Family 2: Vessels			
4 first generation drill ships	operations	176	Dome
semisubmersible ice cutter	feasibility	155	Sun
Kirgoriak experimental icebreaker	operations	27	Dome
2 LNG carriers and terminal development	regulation	1,139	PetroCanada
dredge	design	100	Dome
swivel drill ship	feasibility	80	Dome
PIPS icebreaking drill vessel	feasibility	n.a.	Dome/Global Marine
round drill ship	predesign	125	Dome
conical drill vessel	construction	100	Gulf
2 icebreaking vessels	construction	200(2)	Gulf
Family 3: Surface Platforms			
air cushion drill barge	prefeasibility	n.a.	Sun
air cushion transporter-100	operations	1.3	Sun
ice platform(3)	operations and decommissioned		Panarctic
platform		0.8	
drill rig		6.0	
subsea equipment		2.75	
under ice well completion system	operations	12.5(4)	Panarctic

Source: Industry interviews

Notes:
(1) The Dome and Gulf caissons should be closer together in price. One or both of these estimates is faulty, but it could not be ascertained which.
(2) Two workboats are also included in this figure.
(3) The cost is for the Drake F-76 well.
(4) This includes the flowline and operation for one year.

techniques tend to build new systems by minimally modifying smaller functional units and assembling them into new packages.

CEDOs IN THE AOPI

The six petroleum companies in the AOPI own the innovations, and in most cases, are the operators, but they do only a small fraction of the development, design and construction work. Data from PetroCanada show that between 80 per cent and 90 per cent of all project expenditures up to the construction phase have gone to CEDOs. Data from Dome show that during one representative period, 58 per cent of personnel costs went to CEDOs. Even in a period when a third firm, Gulf, had no active development projects and was trying to employ in-house staff to the fullest, it is estimated that 25 per cent of research expenditures went to CEDOs. When Gulf initiated major hardware projects, their CEDO hirings rose greatly in proportion to the work. A fourth firm, Panarctic, had only 152 employees, and undertook its large exploration and development projects almost entirely through contract means.

These few data points on the firms are consistent with other sources. More than two thirds of all R&D projects undertaken for the Arctic Petroleum Operators' Association (a co-operative industry group) have been carried out by CEDOs.[10] A survey of Canadian arctic and ocean industry groups shows that CEDOs carry out more than four times as much R&D as the petroleum companies.[11] In the case of the 19 system innovations specifically studied by this research, every one had major CEDO involvement.

The AOPI illustrated a different commercial strategy and organisation of industry to what is known by the organisation literature. Yet subcontracting for nearly all project work is routine in the petroleum industry at large. *Nickle's Canadian Oil Register* lists 13 separate categories of firms in the Canadian petroleum industry, of which only one is the petroleum company and all others are subcontractors.[12] Out of 200,000 people employed in the industry,[13] only 64,000 work for the petroleum companies; 18,000 are consultants of all kinds and 37,000 are in engineering construction firms.[14] Producing from a typical conventional oil well in Canada may involve the participation of up to 31 firms in addition to the petroleum company that owns the resource.[15] Jenkin, studying the offshore supply industry in the North Sea, describes it as essentially a huge subcontracting network with the petroleum company at its centre.[16]

We must be careful in interpreting such statistics for the case of CEDOs. The term consultant is not rigorously defined in the oil industry and includes a great range of specialities. Basically, the

CEDO is a consulting engineering firm, which means it must neither construct nor sell hardware, only advice.[17] However, the term CEDO is more than this; it is not limited to engineering, nor to independent consulting firms. It includes all purveyors of expertise needed to research, design and manage technological systems. This may occasionally include construction and turnkey ownership, although this is not the case in the AOPI.

For the present research, 80 CEDOs were found to be involved with the AOPI innovations studied; 14 were interviewed in depth and are listed in Table 3. It shows their average size is 24 professional employees, in a range from 1 to 68. They fall into a typology of 9 separate categories. Thus we see the term CEDO includes a wide range of actors both in the public and private sectors. The AOPI case study shows how extensive the organisation of technological expertise in the consulting mode is in Canada. The one feature these 9 different types of CEDOs have in common is that they deal only with the knowledge aspects of the innovation process and leave the physical construction and operation to others.

CEDO ROLES IN TECHNOLOGICAL INNOVATION

The CEDO roles were chosen for investigation because they describe the CEDOs' characteristic functions in the innovation process, for which no prior studies exist. There are three main types of roles for

TABLE 3
The CEDO Sample

CEDO Type	CEDO Interviewed	Number of Professionals	Founding Date	Affiliation	Quantity Recorded
Individual	"X"	1	1979	Independent	3
Incorporated Individual	"Y"	3	1980	Independent	9
Commercial Independent:					44
	Fenco(1)	12	1969	Lavalin	
	Acres(1)	12	1970	Independent	
	Swan Wooster(1)	10	1971	Independent	
	FG Bercha	18	1974	Independent	
	P. Hatfield	5	1974	Independent	
	German & Milne	18	1922	Independent	
Commercial Laboratory	Arctec	20	1973	SNC	5
Government Laboratory	NRC Ship Laboratories				
	(Ottawa)	25	1950	Federal	
	(St. John's)	68	1983	Government	4
Crown Corporation Development Centre	Nordco	62(2)	1975	Newfoundland Government	1
University Institute	C-CORE	35(2)	1975	Memorial University	1
Design Group	TriOcean	25	1976	Independent	10
Classification Society	Lloyd's Register	12	1760	Lloyd's Register UK	4

Source: Industry interviews
Notes: (1) Data refer to the Arctic Groups only within the firms.
(2) This is the total number of employees.

which CEDO participation will be examined: organiser of the project; actor within the individual project; and actor at the industry level. Within each of these main classes there are several specific roles the CEDOs assume.

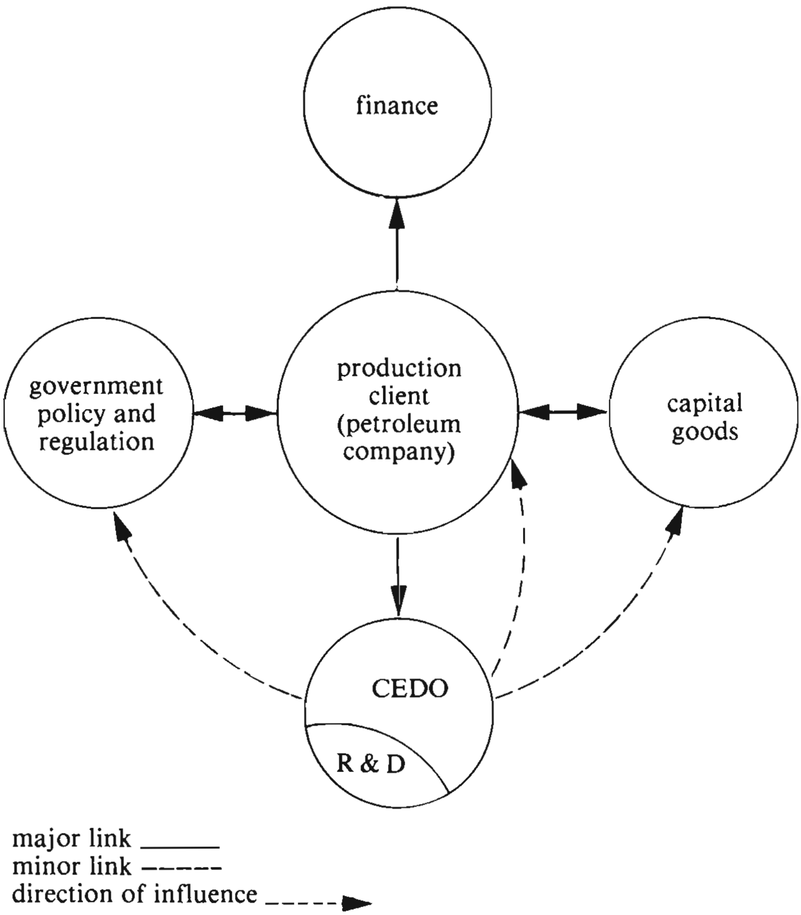
Project Organiser

The first role has little to do directly with innovation, but it is essential for understanding the overall relation of CEDO to client. In light of Perrin's research,[18] we should expect to see the larger CEDOs playing an important role in organising projects. Perrin's concept is that large engineering firms organise the project actors into four poles (finance, capital goods, R&D, production client) and drive and mediate information exchanges at the centre, or *carrefour,* of these poles.

The AOPI is quite different. Despite the fact that the CEDOs carry out nearly all the technology research, development and design, it is the petroleum company that is the *carrefour,* initiating, organising and managing the projects. The case study data show this for all the innovations studied. The AOPI *carrefour* is shown as Figure 1, where the CEDO is one of the poles. The CEDO pole absorbs the R&D pole as part of its characteristic function. The CEDO acts as secondary *carrefour,* with separate links to the government and capital goods poles, but the links are much weaker than those of the client. In the AOPI, government is a major actor in all stages of petroleum activity, so it is included as an additional pole. CEDOs carried out important policy development contracts for government relating to the innovations studied — 8 such cases were found. For example, Fenco dealt directly with instrument companies and chemical firms to design the ice platforms for Panarctic. Fenco also dealt informally with technical experts in government regulatory and research agencies concerning the ice platform projects, and independently carried out arctic offshore technology contracts for other branches of government. However, Panarctic controlled all the formal relations with government, authorised Fenco's purchase of capital goods, and obtained all substantial capital goods by itself or authorised the construction contractor to do this. While every case is slightly different, the model shown in Figure 1 seems generally to hold. As will be shown later, the CEDOs have little input to the management, engineering, procurement and construction supervision (MEPC) functions where they would be more closely involved with the capital goods sector.

It should be noted that this model may only represent the case of innovation in large marine structures while the AOPI is in its present stage of exploration for petroleum. In the next stage, development, construction activity will be greatly expanded and stabilised. CEDOs

FIGURE 1
AOPI Carrefour



linked to large MEPC contractors may develop and move into a more central *carrefour* position. The weak link between the CEDO and capital goods poles in the AOPI typifies the more general problem of Canadian CEDOs in moving from the design phase into full MEPC work.[19] The integrated chain of events in the technology development process is often broken, and the lucrative MEPC work for large projects handled by foreign CEDOs.

Innovation Roles at the Project Level

The most obvious roles are played within the context of the individual project. There are three types to be considered here: the source of the innovation; the elaboration of innovation; and the execution of innovation. These roles are related to a framework of the innovation process in the AOPI that is based directly on the standard process of execution of engineering projects. While this is well known to those involved with large engineering projects, it is a framework that is new to the innovation literature, so the projects steps are summarised in Table 4. Every project studied in the AOPI followed a sequence of stages within this framework (although not all projects were completed), so it is useful to relate the CEDO roles to it.

TABLE 4
Project Phases

Project Phase	Project Stage	Description
Predesign	prefeasibility	first attempt to explore the basic ideas, concepts or configuration.
	(research)(1)	
	feasibility	further elaboration which makes a first good cost estimate and decides if a project is worth being fully developed.
Design	preliminary design	establishes engineering credibility. Designs may be sent to ship yards to solicit bids.
	(research)(1)	
	regulation	hiatus from project flow. Initial document preparation, strategy development, participation in hearings, subsequent redesign if needed.
	detailed design	complete design of all elements so contractor can bid on package.
Construction	procurement	purchase equipment and supplies.
	project management	devising and implementing the plan to build.
	construction supervision	ensuring the construction is done to design specifications.
	construction	building, assembling, emplacement.
Operations	preoperation	start up, run in, stability tests, sea trials.
	(research)(2)	
	training	training personnel.
	technical assistance	specialised expertise may be hired to investigate production problems.
	production	normal system operations.
Decommissioning	decommissioning	expert advice, sale, salvage.

Notes: (1) Primarily aimed at establishing design criteria.
(2) May be needed to investigate and remedy immediate production problems.

(i) The CEDO as Source of Innovation

The most important role a CEDO could play would be as the source of innovation, in other words, the inventor of the new technology.

Unfortunately, the AOPI innovations have no clear cut beginnings as inventions. The new technologies listed in Table 2 are mostly incremental modifications of existing concepts and new system arrangements of existing hardware components. Patents, which usually are taken to denote an invention, are few and unimportant. Of the 42 Canadian patents registered by the AOPI petroleum companies, only 3 were incorporated into functioning systems. CEDOs had no independent patents. AOPI contracts always require them to sign away all patent rights. Thus, the CEDO is not the inventor of the new systems. We could still consider the CEDO as an important source of innovation if it were found to be the instigator of projects. That is, the CEDO may take an idea that is already widely known by the engineers in the AOPI community and, through its own initiatives, interest a petroleum company to investigate it further.

Instigation can be measured directly by counting unsolicited proposals. Doing this for the innovations studied shows this kind of instigation does not exist, as only one case was found and that system was never constructed. All the interviews with CEDOs and petroleum company managers confirmed that unsolicited proposals can be found in the industry, but that they are few, and deal mostly with minor elaboration of existing applied research programs. However, many of the contracts given to CEDOs may arise as a result of informal initiatives by the CEDO. To understand the CEDO role in the AOPI, it is necessary to abandon the concept of discrete beginnings for innovations, which has been widely accepted by earlier innovation studies.[20] House has shown how the oil industry as a whole in Canada is a tightly-knit community.[21] This study shows this to be even more so for the subgroup of the AOPI.[22] In the AOPI, innovations arise from a pool of ideas widely held by a community of designers. This concept gives a much greater role to the CEDO, for it is active in shaping the development within the formal context of a project. Thus we need to focus on the CEDO's work during the initial project stage, which is prefeasibility.

The data show that CEDOs controlled the prefeasibility stage in only five cases (three for Sun, one each for PetroCanada and Dome). All these cases had the common feature that the client initially lacked expertise as it was moving into a new project area. PetroCanada's and Dome's strategy in each case was to hire the consultant only to get the project underway; in-house management capability was quickly built up. Sun abandoned the AOPI after initial work. The long term aim for the firms that stayed in the arctic offshore was to build up sufficient management capability to do prefeasibility work in-house. This would seem to imply a limited CEDO role. However, this is not the case. Once in-house management capacity exists, there may be a full partnership between CEDO and client during prefeasibility where new ideas are generated together. In the Arctic pilot project and in the Panarctic ice platform, the two innovations studied in depth, there was an active CEDO participation in the development of ideas. Frequent informal consultations occurred during all project stages which often led to the formulating of new subprojects. For Dome and PetroCanada projects it was noticed that the very small CEDOs (Individual and Incorporated Individual types) can work so intimately with the client, almost as permanent employees, that there is really no distinction between client and CEDO. Dome has gone even further to reduce institutional barriers between CEDO and client, thereby encouraging this informal interaction as much as possible. Dome uses some CEDOs as "house consultants", meaning that the firm is guaranteed a minimum monthly amount of work for an indefinite period in return for priority attention to Dome work. The CEDO must also ask Dome's permission to work on other contracts that could be competitive with those of Dome. Dome even makes a practice of hiring CEDOs to participate in group "brainstorming" sessions to maximise the input of expertise in prefeasibility studies and for special problems. Although the individuals often represent competing companies, it is reported by a Dome manager that the sessions are very productive.

We can conclude that while CEDOs do not have an important role as an independent source of innovation, they are very important as a source of ideas within the project system. Some of the original ideas were found to arise from the CEDO alone (e.g., the articulation for Imperial's octagon caisson by the firm APD, the ice platform for Panarctic by Fenco and the air cushion drilling barge and ice cutter for Sun by Arctic Engineers and Constructors), but it would take highly focussed studies to display the patterns more clearly. With the present data we can only conclude that the responsibility is shared and that innovative ideas arise from the recurring and informal interactions between client and CEDO. The implication of this finding is that future innovation research must study both actors at the same time — a misleading account would be painted by ignoring either one.

(ii) Elaboration of Innovation

The second innovation role within the context of the project is that of elaborator of innovation. This term refers to the kind of project work that occurs after prefeasibility, where general function and configuration are established, in order to prepare the design for construction. It means something like development in the term R&D, except that for the AOPI, the prototype is usually the working system, so there is not the extensive feedback from operations and subsequent redesign over many generations of the technology.

Using the standard framework of project stages presented in Table 4, we can see that elaboration occurs during feasibility, predesign and detailed design stages. These three stages are on a continuum that leads from generality to increased specificity. Dividing the continuum into separate stages is somewhat arbitrary, but there is a basic division between prefeasibility and the next three stages, which elaborate the concept and work within the boundaries of the established configuration and function to create the new system. While the innovation process obviously carries on into elaboration, it is likely that the more elaboration proceeds from feasibility to design stages, the weaker becomes the connection with innovativeness and the more the work becomes standard project work.[23] Data quoted earlier for Gulf, Dome and PetroCanada show that CEDOs did almost all the elaboration work for these companies' projects. Detailed interviews with Dome, PetroCanada and Panarctic showed that these petroleum companies acted as managers in all projects, hiring CEDOs for the great bulk of engineering work.

A few interesting patterns stand out in variations of the extent of CEDO participation. They allow the generation of several hypotheses that may be important for elaboration in future research. There are two dimensions that seem to be important in describing exceptions to the general pattern of CEDO use. These are the scope of CEDO input and the amount of CEDO involvement. The scope varies from one extreme of the CEDO having great freedom in making general design decisions to the other extreme of being highly constrained by the client and given very specific directives. There are three scope hypotheses:

1) The more commercial importance an innovation has, the smaller the scope of the CEDO's role in elaboration will be;

2) Growth of in-house staff limits the scope of the CEDO role in elaboration of innovation, but only weakly; and

3) Increasing the intimacy of the relation between CEDO and client reduces the scope of the CEDO's role.

The second dimension that seems to control the CEDO role refers to the magnitude of CEDO involvement, or the proportion of work done by contract as opposed to in-house. Two hypotheses will be summarised here:

1) Petroleum companies have a fixed strategy for CEDO use so that as project work grows and more staff are needed, the ratio of CEDO personnel to in-house personnel remains constant. It is obvious that this hypothesis could be extended to state that as the work load diminishes, then the CEDO personnel will be sacrificed before the in-house staff.

2) As the project becomes more routine, the magnitude of CEDO use decreases, but only slightly.

The reasoning leading to these hypotheses is discussed fully in the original research. Because no quantitative data were available to describe scope and amount of involvement, and because the data base was very small in this instance, the hypotheses must be considered as tentative suggestions for future evaluation.

(iii) Execution of Innovation

The third general project level innovation role is execution of innovation. This is a term chosen to group project activities that do not develop the configuration or function of the new technology, but take the results of design and turn them into a physical system. Unlike the previous two roles, source and elaboration of innovation, execution consists of a variety of quite separate roles. In keeping with the terminology used in Table 4, they are defined as procurement, construction supervision, project management, and special services. This parallels what the innovation literature commonly refers to as prototype operation, manufacturing and marketing. The execution roles do not involve significant original input because the configuration of the new systems in the AOPI has already been fixed as the outcome of the design phase. No instances of innovation were found to arise in the AOPI during project execution. Only one case was found where the CEDO interviewed did project management on a major system. TriOcean was the only CEDO that was found to integrate procurement and construction supervision, but in its case the hardware was relatively small mechanical technologies such as blowout preventers, where it acted as a custom assembler.

This situation exists despite the efforts of the major CEDOs to use their feasibility studies to lead into full MEPC work. The petroleum companies handle all project management and procurement roles themselves. (Two cases were found where they awarded procurement to the construction contractor, but this survey was not exhaustive.) In fact, two petroleum companies, Dome and PetroCanada, created subsidiaries specifically to carry out project management and operations functions. Another firm, Panarctic, has been characterised as essentially a MEPC contractor set up just to specialise in offshore arctic petroleum. Only in construction supervision does the AOPI CEDO have a chance of work, and the data show it is still very limited (e.g., Fenco for the ice platform and Swan Wooster for the Dome caisson island).

The last category of project execution role is special services. There are two types of special services: expert witness and watchdog. During the regulatory phase of projects, CEDOs are likely to be placed on the stand by the client to defend or explain specific parts of the project design. So far in the AOPI, only one project has been involved in regulatory hearings, but production systems in the Beaufort Sea had to be examined by government before they could be constructed. Two interviewees claimed that CEDOs are often hired in an expert witness capacity just to enhance the legitimacy of a design decision. If a consultant is prepared to support a particular design, it implies an impartial external review has been made, and an assurance that accepted industry practice has been followed. The greater the consultant's reputation, the weaker the challenges to the design decisions will be.

The next special service role is watchdog. There is a need to hire CEDOs to check design concepts so the clients will have second opinions on them. Thus, it is common practice (eight instances were noticed) to hire one CEDO to monitor ongoing programs of another and to review completed work.[24] This role is especially important for ice tank tests where the techniques are only approximate and results vary according to the kind of model ice, the different tank dimensions, and the scale of models. For this reason, the same structure is routinely tested in several different tanks.

The implication of these roles is that a full understanding of the process of innovation and industrial organisation can only be had by very thorough study of each specific sector and its political and social contexts.

Evolution of Technology at the Industry Level

The roles discussed previously unfold within the context of the individual project. There is another level at which the CEDOs play crucial roles within the AOPI, at the level of the entire industrial community. Technological advance is made within the context of individual projects, but taken as a whole, over time, the summation and interaction of individual corporate projects present a coherent pattern of evolution of technology.[25] At the industry level, it can be hypothesised that the CEDO has a unique and crucial role. It acts as a centralised pool of expertise available to the entire AOPI for the purpose of creating technology.[26] Because the CEDO acts between individual projects and petroleum companies, it should be a central actor in this long term evolution of AOPI technology.

The case study data indicate that the CEDOs do work as a centralised pool of expertise used by all the petroleum companies. Project lists of every CEDO studied (except for the Individual type firm) show that all have worked for a wide variety of governmental and petroleum industry clients. All CEDOs except the one-man firm have worked for at least 3 different AOPI petroleum firms.

There are three main implications of this role suggested by the AOPI data. First, one would expect that the industry level role causes the innovations to be more homogeneous and to fit together into more closely related groups than if it were not present. Some homogeneity would result in any case because there is a high degree of co-operation between the petroleum companies in the AOPI, but the CEDO would strongly accentuate this because it is relatively free to transfer design concepts and techniques among the companies of the AOPI.

The key factor facilitating transfer is that the CEDO is not seen as a competitor by its clients. The CEDO produces technology, not oil and gas, and in general, the petroleum companies are uninterested in the limited commercial possibilities arising from the technological innovations.[27] All the CEDO can do having developed the technology is sell more expert services; it does not control AOPI technology by patents or licensing so cannot dictate on unfavourable terms to the client. As a result, the CEDO usually has access to confidential environmental and design data. The CEDO is then free to take the data and experience and apply them to the project of another petroleum company provided that the competing companies do not see each other's confidential data.[28] In this way, the CEDO builds up expertise that transcends what any individual petroleum company could achieve and applies it to all companies. The CEDO is expected to be a crucial mechanism to improve the development of technology and break down the impediments of corporate barriers.

The second implication of the industry level role is that it should enhance the efficiency of the AOPI in developing new technology. Under present conditions, even with the extensive involvement by CEDOs, there is a critical shortage of offshore arctic engineering expertise in the AOPI. Obviously, if each petroleum firm attempted to build up full in-house engineering design teams to handle the intermittent labour peaks instead of hiring CEDOs only when needed, the shortages would be seriously exacerbated. There would not be enough expertise in arctic and offshore engineering to supply the needs of every petroleum company. Companies unable to build up teams would be unable to execute projects. With the existence of the industry level role, the AOPI can probably produce innovation with less manpower.

The other aspect of efficiency is that the need for CEDO services in any individual project is quite episodic. Organisation of expertise into a central pool gives a high utilisation factor because there are always different projects to be done. The high utilisation factor in turn would allow increased specialisation within the CEDO pool which would further increase efficiency. Increased homogeneity of the technologies would also allow them to be produced faster.[29]

The third implication is that the industry level role should facilitate entry by novice petroleum firms into the AOPI. This has important policy implications where concern exists over monopolies, barriers to entry and national industrial development. All petroleum companies, even the smallest, possess a core of expertise in-house relating to the basic geological, geophysical, engineering and marketing operations of the oil and gas industry. Thus, if a company wishes to enter the AOPI independently, it can do so relatively quickly and easily because the expertise needed to adapt to the arctic offshore is almost completely available by contract. As the Panarctic example shows, all that is needed is to maintain a small management structure. This mechanism maybe a major reason for such important participation in the AOPI by Canadian firms like Dome, PetroCanada and Panarctic, which all started out in the AOPI as much smaller companies than the other three multinationals.

CONCLUSION

CEDOs are key actors in the creation of new technology for the AOPI, by the magnitude and by the quality of their involvement. An attempt has been made to explore the diverse roles CEDOs play in innovation and to lay out the main causal factors and implications. Because the research was discovery-oriented, that is, it aimed to generate hypotheses and a theoretical structure, the descriptions of the roles and their implications should be considered as tentative. As an exploration of a new topic, this research will be meaningful if it can stimulate further investigation of the analytical structure it has attempted to create.

NOTES AND REFERENCES

1. Alberto Araoz (ed.), *Consulting and Engineering Design in Developing Countries,* International Development Research Centre, Ottawa, 1981. Much of this research is in the form of working papers, so not readily available. This is the case for important contributions by Mario Kamenetzky (*Engineering and Preinvestment Work,* report submitted to IDRC, Ottawa, 1976) and by Anil Malhotra (*Consulting and Engineering Design Organisations,* report submitted to IDRC, Ottawa, 1976). Two studies not covered in Araoz's survey are: John Roberts, 'Engineering Consultancy, Industrialization and Development' in C. Cooper (ed.), *Science, Technology and Development,* Frank Cass & Co., London, 1973, pp. 39-61 and Padma Desai, *The Bokaro Steel Plant,* North-Holland, New York, 1972.

2. Jacques Perrin, *L'Engineering: Terminologie et Fonction Economique,* Industrie et Technologie Etude Speciale no. 9, OECD Development Centre, Paris, 1976.
3. See Milutin Perichitch, *Engineering Capacities for Industrial Development,* Industry and Technology Occasional Paper No. 23, OECD Development Centre, Paris, 1976.
4. For example, see Kirk Thompson, *Technology Transfer: Strengthening Canada's Consulting Companies in Developing World Markets,* Institute for Research on Public Policy, Toronto, 1984. Recently the National Research Council has awarded a contract for a major survey of CEDOs in Canada. The author's doctoral thesis, from which this paper is taken, was unable to find any major theoretical studies of CEDOs that preceded it. See Scott Tiffin, *The Involvement of Consulting and Engineering Design Organizations in Technological Innovation for the Canadian Arctic Offshore Petroleum Industry* (PhD thesis, Institut d'histoire et de sociopolitique des sciences, Université de Montréal, 1983). This study is also available from the Technological Innovation Studies Program, Department of Industry, Trade and Commerce, Ottawa, 1984.
5. Statistics Canada, *Consulting Engineering Services,* catalogue S63-528, Statistics Canada, Ottawa, 1974; Statistics Canada, *Consulting Engineering Services,* Statistics Canada, Ottawa, 1978; Peter Barnard Associates, *Consulting Engineering in Canada: An Update,* Ministry of Supply and Services, Ottawa, 1981.
6. Of course, there has been occasional reference to consulting, but the remarks seem to be very few and undeveloped.
7. Major et Martin Inc., *Les Activités des Sociétés Québécoises de Génie Conseil,* Major et Martin Inc., Montréal, 1981.
8. J.D. House, *The Last of the Free Enterprisers: The Oilmen of Calgary,* Macmillan, Toronto, 1980, in a study of the sociology of the Canadian petroleum industry, used the same discovery-oriented approach based on Barney Glaser and Anselm Strauss *The Discovery of Grounded Theory,* Aldine-Atherton, Chicago, 1967 because of the lack of prior data on his topic.
9. This is the potential investment figure. It includes systems that were studied but not built; the figure for those actually constructed or under construction is $880 million.
10. APOA, *Description of Research Projects,* vols. 1, 2, 3., Arctic Petroleum Operators' Association, Calgary, 1981.
11. Acres, *Inventory of Canadian Research and Development Capabilities for Engineering in Cold Regions,* National Research Council, Ottawa, 1978.
12. Carl Nickle, *Nickle's Canadian Oil Register 1980-81,* C.O. Nickle Publications, Calgary, 1980.
13. Z.M. Kubinski, *The Small Firm in the Albertan Oil and Gas Industry,* Technological Innovation Studies Program Research Report, Department of Industry, Trade and Commerce, Ottawa, 1979, p. 1.3.
14. Nickle, *op. cit.*
15. Energy Services Association, *A Typical Central Alberta Oilwell,* Energy Services Association, Red Deer, Alberta, 1981.
16. Michael Jenkin, *British Industry and the North Sea,* Macmillan, London, 1981.
17. See: FIDIC, *about FIDIC,* Fédération Internationale des Ingénieurs-Conseils, The Hague, 1979/1980; ACEC, *The Consulting Engineer . . . A Better Alternative,* Association of Consulting Engineers of Canada, Ottawa, no date.
18. Jacques Perrin and Bernard Réal, L'Industrie des Biens d'Equipement Mechanique et l'Engineering en France at en Allemagne de l'Ouest, IREP, Université de Grenoble, Grenoble, 1976.
19. This point is also made by Shirley Carr and Robert Blair (chairpersons), *Major Canadian Projects, Major Canadian Opportunities,* a report by the Consultative Task Force on Industrial and Regional Benefits from Major Canadian Projects, Department of Industry, Trade and Commerce, Ottawa, 1981.

20. For a good review and critique of such studies, see R. Nelson and S. Winter, 'In search of a Useful Theory of Innovation', *Research Policy*, 6, 1977, pp. 36-76.
21. House, *op. cit.*
22. Tiffin, *op. cit.*
23. The AOPI data are not fine enough to illustrate this; it is only an assumption.
24. This is probably a widespread role. Padma Desai *(op. cit.)* describes the same role in detail for design of a steel plant in India.
25. See Devendra Sahal, *Patterns of Technological Innovation*, Addison-Wesley, Reading, Mass.,1981.
26. Nathan Rosenberg, *Perspectives on Technology*, Cambridge University Press, London, 1976, p. 143, has stated that the machine tool industry played a key role in the evolution of many industries in the 19th century because it specialised in the basic elements for their production processes. The machine tool companies acted as a central technology development group; this is somewhat similar to the industry level role in the AOPI.
27. This point is made more fully in the original work. Basically, it results from the fact that the AOPI is rather isolated from the rest of the world oil industry due to its geographical peculiarities: hence there are few markets for the specialised innovations.
28. This is especially true for geological and geophysical consultants. The one case where it was seen in the AOPI was with Swan Wooster and its caisson contracts.
29. There were no AOPI data to illustrate this point, but it seems reasonable.